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Ring-Wave Measurements From Natural Rain

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Abstract- We present preliminary results of our efforts to measure ring-waves generated by natural rain. Winds at sea are monitored by remote sensing of radars observing sea surface roughness. Yet rain also roughens the sea surface. Improved understanding of sea-surface roughness during rain contributes to better measurements of winds and rain at sea.

I. INTRODUCTION

Rain and wind measurements in oceanic regions are making significant contributions to weather monitoring and climate studies. Spaceborne instruments such as altimeters and scatterometers measure power levels of microwave echoes from the sea-surface and since echo strength correlates with sea-surface roughness, particularly small-scale roughness, any processes that affects sea-surface roughness can modify measurements. Nearly ubiquitous winds roughen the sea surface, so most data inversion algorithms deal with wind exclusively. Rain also alters radar signals. Attenuation and scattering by rain in the atmosphere are popular topics of research due to the large interest in weather radars. The effects of rain on microwave scattering from the sea-surface have, however, only recently become an active research topic.

When a raindrop hits a water surface, it can generate a cavity with a crown, which collapses to form a vertical stalk of water, which subsides to spawn rings of gravity-capillary waves that propagate outward Worthington (1), Le Méhauté *et al.* (2, 3). At grazing angles, Wetzel (4) found that stalks are the dominant feature contributing to backscattered power. At incidence angles used from space, studies by Bliven and Giovanangeli (5) and Sobieski and Bliven (6) show that the dominant scattering mechanism is Bragg scattering from ring-waves. Much more has been learned about microwave scattering from rain-roughened surfaces by conducting laboratory experiments and numerical modeling. For example see Braun *et al.* (7), Bliven *et al.* (8, 9, 10), Craeye *et al.* (11, 12, 13), LeMaire *et al.* (14) and Sobieski *et al.* (15).

Such results are being used to enhance scattering models, which compute backscattered power values for altimeters, scatterometers and rain radars by using various sea-surface spectral models. For example, see the Université Catholique de Louvain UCL composite model that is amply documented by Guissard *et al.* (16&17), Lemaire *et al.* (18, 19, 20) and Sobieski *et al.* (21).

The goal of this investigation is to ascertain the feasibility of measuring ring-waves generated by natural rain.

II. EXPERIMENTAL CONFIGURATION

The setup for ring-wave measurements for natural rain was as follows. These experiments were conducted outside in a field near the Rain-Sea Interaction Facility at NASA Wallops Flight Facility. We installed a 1.5mx1mx1m tank and filled it with fresh water to a depth of 0.8m. Sensors that we normally use in the rain laboratory were configured to work outside. Power cables and sensor output signals were linked to an adjacent building that housed PC's for digitizing and recording data at a sampling rate of 64 Hz.

Data products were computed for each minute of observations from the 16 bit data. Surface elevation was measured using a capacitance wire probe. The system provides an analog voltage that is linearly related to surface elevation relative to the mean water level. Because craters, crowns and stalks do not propagate, the capacitance probe measures only the desired feature -waves. Wave spectra were computed from the sampled datasets with a resolution of 0.25 Hz. A commercial optical rain gage provided an analog signal that is proportional to rainfall rate, while a commercial wind sensor provided analog signals of wind speed and direction

III. RESULTS

A 40 minute spring shower provided us with a high-quality data set from the field site.. From the elevation, data we computed the height spectra for each minute during the storm.

Figure 1 shows the ring-wave spectra and height variance with respect to rainrate for each minute of the storm. Certainly the spectral shape closely resembles ring-wave spectra from laboratory experiments, i.e. these normalized ring-wave spectra have a log-Gaussian shape. Likewise the ring-wave variance increases Figure 1 shows that the ring-wave variance ranges from about 10^{-4} to 10^{-2} cm^2. These ring-waves are tiny. Yet in this basin during this storm event, ring-waves are dominant compared to wind-generated waves.

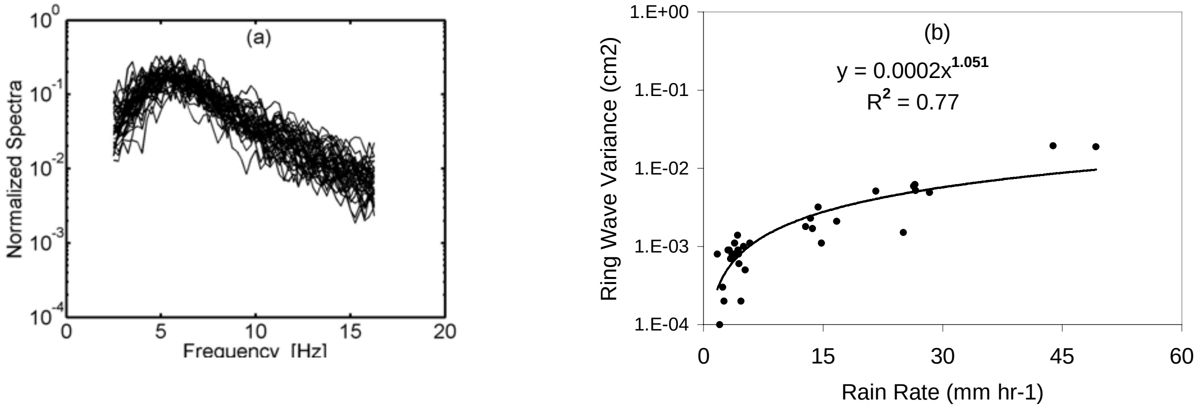

Figure 1. Normalized ring-wave spectra and ring -wave variance from a rain event.

The ring-wave spectra have a similar shape, i.e. the maxima occur at almost the same frequency, the bandwidths are quite narrow and comparable, and the roll-offs are asymmetric with the low frequency side decaying faster than the high frequency tail. These are typical traits of the log-Gaussian spectral representation for ring-waves, which was first promoted by Sobieski in (8). He conceived it for natural rains from the theoretical analysis of single drop impacts by Le Méhauté (2&3). The log-Gaussian form has been used successfully to model ring-waves spectra for water surfaces roughened by artificial rain by Bliven *et al.* (9) and LeMarire *et al.* (14). In all cases, these spectra show that a log-Gaussian spectral representation is suitable for modeling ring-waves generated by natural rain.

IV. CONCLUSIONS

The data presented in this paper demonstrate that we have successfully adopted laboratory equipment and developed techniques to measure ring-waves outside in natural rain. Recent laboratory results by LeMaire (14) show that ring-wave spectral features are sensitive to the drop size distribution as well as the rain rate, so we were also motivated to develop the Rain Imaging System that allows us to characterize rain in terms of both drop size distribution and rain rate. For further details, see Bliven *et al.* (22)

Acknowledgements.

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References

[1] Worthington, A.M., A study of splashes. *Proc. Royal Soc. of London*, 34, 217-229, 1882.

[2] LeMehaute, B., Wang, S. and Lu, C.C., Spikes, domes, and cavities. *J. Int. Assoc. of Hydr. Res.,* 5, 583-602, 1987.

[3] LeMehaute, B., Gravity-capillary rings generated by water drops. *JFM*, 197, 415-427, 1988.

[4] Wetzel, L.B., On the theory of electromagnetic scattering from a raindrop splash. *Radio Science*, 25(6), 1183-1197, 1990.

[5] Bliven, L. and Giovanangeli, J-P., An experimental study of microwave scattering from rain- and wind-roughened seas. 14(5), *IJRS*, 855-869, 1993.

[6] Sobieski, P.W. and Bliven, L.F., Analysis of High Speed Images of Raindrop Splash Products and Ku-band Scatterometer Returns, *IJRS*, 16: (14) 2721-2726, 1995.

[7] Braun N., Gade M. and Lange P.A., The effect of artificial rain on wave spectra and multi-polarisation X band radar backscatter. *IJRS*, 23(20): 4305-4323, 2002.

[8] Bliven, L.F., Sobieski, P.W. and Craeye, C., Rain Generated Ring-Waves: Measurement and Modelling for Remote Sensing. *IJRS*, 18(1), 221-228, 1997.

[9] Bliven, L.F., Branger, H., Sobieski, P.W. and Giovanangeli, J-P. An Analysis of Satterometer Returns from a Water Surface Agitated by Artificial Rain. *IJRS*, 14(12), 2315-2329, 1993.

[10] Bliven, L.F. and Elfouhaily, T.M., Presenting the Rain-Sea Interaction Facility. NASA Ref. Pub. 1322, 51p., 1993.

[11] Craeye, C., Radar signature of the sea surface perturbed by rain. PhD thesis, UCL. 1998.

[12] Craeye C., Sobieski P.W., Bliven L.F., and Guissard, A., Ring-waves generated by water drops impacting on water surfaces at rest. *IEEE J. Ocean. Eng.*, 24: (3), 323-332, 1999.

[13] Craeye, C., Sobieski, P.W. and Bliven, L.F., Scattering by artificial wind and rain roughned water surfaces at oblique incidences. *IJRS*, 18, 2241-2246, 1997.

[14] LeMaire, D., Bliven, L.F., Craeye, C. and Sobieski, P.W., Drop size effects on rain-generated ring-waves with a view to remote sensing applications. *IJRS*, 23, 2345-2357, 2002.

[15] Sobieski, P.W., Craeye, C. and Bliven, L.F., Scatterometric signatures of multivariate drop impacts on fresh and salt water surfaces. *IJRS*, 20: (11) 2149-2166, 1999.

[16] Guissard, A., Baufays, C. and Sobieski, P. W., Fully and non-fully developed sea models for microwave remote sensing applications. *Remote Sens. Environ*., 25-38, 1994.

[17] Guissard, A., Sobieski, P.W. and Baufays, C., A unified approach to bistatic scattering for active and passive remote sensing of rough ocean surfaces. *Trends in Geophys. Res*., 43-68, 1992.

[18] Lemarie, D., Non-fully developed seas state characteristics from real aperture radar remote sensing. PhD thesis, UCL, 1998.

[19] Lemaire, D., Sobieski, P.W. and Guissard, A., Full-range sea surface spectrum in nonfully developed state for scattering computations. *IEEE Trans. Geosci. Remote Sens*., 1038-1051, 1999.

[20] Lemaire D., Sobieski P.W., Craeye C. and Guissard, A. A Two-scale models for rough surface scattering: Comparison between the boundary perturbation method and the integral equation method. *Radio Science*, 37 (1):2345-2357, 2002.

[21] Sobieski, P.W., Guissard, A. and Baufays, C., Synergic inversion technique for active and passive microwave remote

sensing of the ocean. *IEEE Trans. on Geosci. and RemoteSens.*, 29(3), 391-406, 1991.

[22] Bliven, L.F., K. Postlewait, and E. McNamara, Measurements of Ring-Waves Generated by Natural Rain, *Belgian Journal of El & Com HF*, 2003(1), 21-29, 2003.